Measurement and Verification

Case Studies, Issues, and Recent Developments

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Overview

- Markets for M&V
- M&V Concepts and Methods
- Issues
- Case Studies in EBCx Projects
- New Protocols
- New M&V Tool Project

M&V Markets

- EE program implementation
- EE program evaluation
- Research
- Performance Contracts
- Future?
  - Superior Energy Performance Certifications
    - Industrial
    - Commercial
  - Carbon Credits/Trading

Savings Calculations (ex-ante)

A Baseline Operation w/ IGV				
Air Volume Flow Rate Profile %	Speed %	IGV Power Ratio [Note 1] %	Power kW	Annual Energy Use kWh/Yr
100%	100%	109%	12.8	51
98%	100%	105%	12.3	74
96%	100%	102%	12.0	96
94%	100%	99%	11.6	267
92%	100%	96%	11.3	362
91%	100%	93%	10.9	436
89%	100%	90%	10.6	244
87%	100%	87%	10.2	602
85%	100%	85%	10.0	750
83%	100%	84%	9.9	782
81%	100%	83%	9.7	1,358
79%	100%	81%	9.5	1,055
77%	100%	80%	9.4	808
75%	100%	78%	9.2	1,003
74%	100%	77%	9.0	801
72%	100%	76%	8.9	454
70%	100%	74%	8.7	835
68%	100%	73%	8.6	774
66%	100%	73%	8.6	697
64%	100%	71%	8.3	1,212
62%	100%	70%	8.2	869
60%	100%	69%	8.1	1,013
58%	100%	68%	8.0	1,048
57%	100%	67%	7.9	940
55%	100%	66%	7.8	562
53%	100%	65%	7.6	1,284
51%	100%	65%	7.6	958
50%	100%	65%	7.6	1,041
50%	100%	65%	7.6	1,467
50%	100%	65%	7.6	631
50%	100%	65%	7.6	509
50%	100%	65%	7.6	456
50%	100%	65%	7.6	319
50%	100%	65%	7.6	152
50%	100%	65%	7.6	122
50%	100%	65%	7.6	122
50%	100%	65%	7.6	84
50%	100%	65%	7.6	122
50%	100%	65%	7.6	23
			12.8	24,379

D Proposed Operation w/o IGV, w/ VFD High Limit & w/ VFD Modulation				
Air Volume Flow Rate Profile %	Speed w/ VFD Modulation %	VFD Power Ratio [Note 2] %	Power w/ VFD Modulation kW	Annual Energy Use kWh/Yr
100%	89.3%	71%	9.1	36
98%	87.6%	68%	8.4	50
96%	85.9%	64%	7.7	62
94%	84.2%	63%	7.3	168
92%	82.6%	60%	6.8	218
91%	80.9%	57%	6.2	248
89%	79.2%	56%	5.9	136
87%	77.5%	53%	5.4	319
85%	75.8%	50%	5.0	375
83%	74.1%	49%	4.9	387
81%	72.5%	46%	4.5	630
79%	70.8%	44%	4.2	466
77%	69.1%	43%	4.0	344
75%	67.4%	40%	3.7	403
74%	65.7%	38%	3.4	303
72%	64.0%	37%	3.3	168
70%	62.3%	34%	3.0	288
68%	60.7%	32%	2.8	252
66%	59.0%	30%	2.6	211
64%	57.3%	28%	2.3	336
62%	55.6%	26%	2.1	223
60%	53.9%	24%	1.9	238
58%	52.2%	23%	1.8	236
57%	50.5%	21%	1.7	202
55%	48.9%	19%	1.5	108
53%	47.2%	19%	1.4	237
51%	45.5%	17%	1.3	164
50%	44.7%	16%	1.2	164
50%	44.7%	16%	1.2	232
50%	44.7%	16%	1.2	100
50%	44.7%	16%	1.2	80
50%	44.7%	16%	1.2	72
50%	44.7%	16%	1.2	50
50%	44.7%	16%	1.2	24
50%	44.7%	16%	1.2	19
50%	44.7%	16%	1.2	19
50%	44.7%	16%	1.2	13
50%	44.7%	16%	1.2	19
50%	44.7%	16%	1.2	4
			9.1	7,603

Savings = 24,379 – 7,603 = 16,776 kWh annually

Note:

- estimate is prior to install
- accurate?
  - data quality
  - analysis
  - assumptions

Measurement and Verification

- Savings are determined from measurements of energy use before and after ECMs are installed, and adjusted to a common set of conditions.

M&V Concepts and Methods

- Guidelines
  - IPMVP (www.evo-world.com)
  - ASHRAE Guideline 14 (www.ashrae.org)

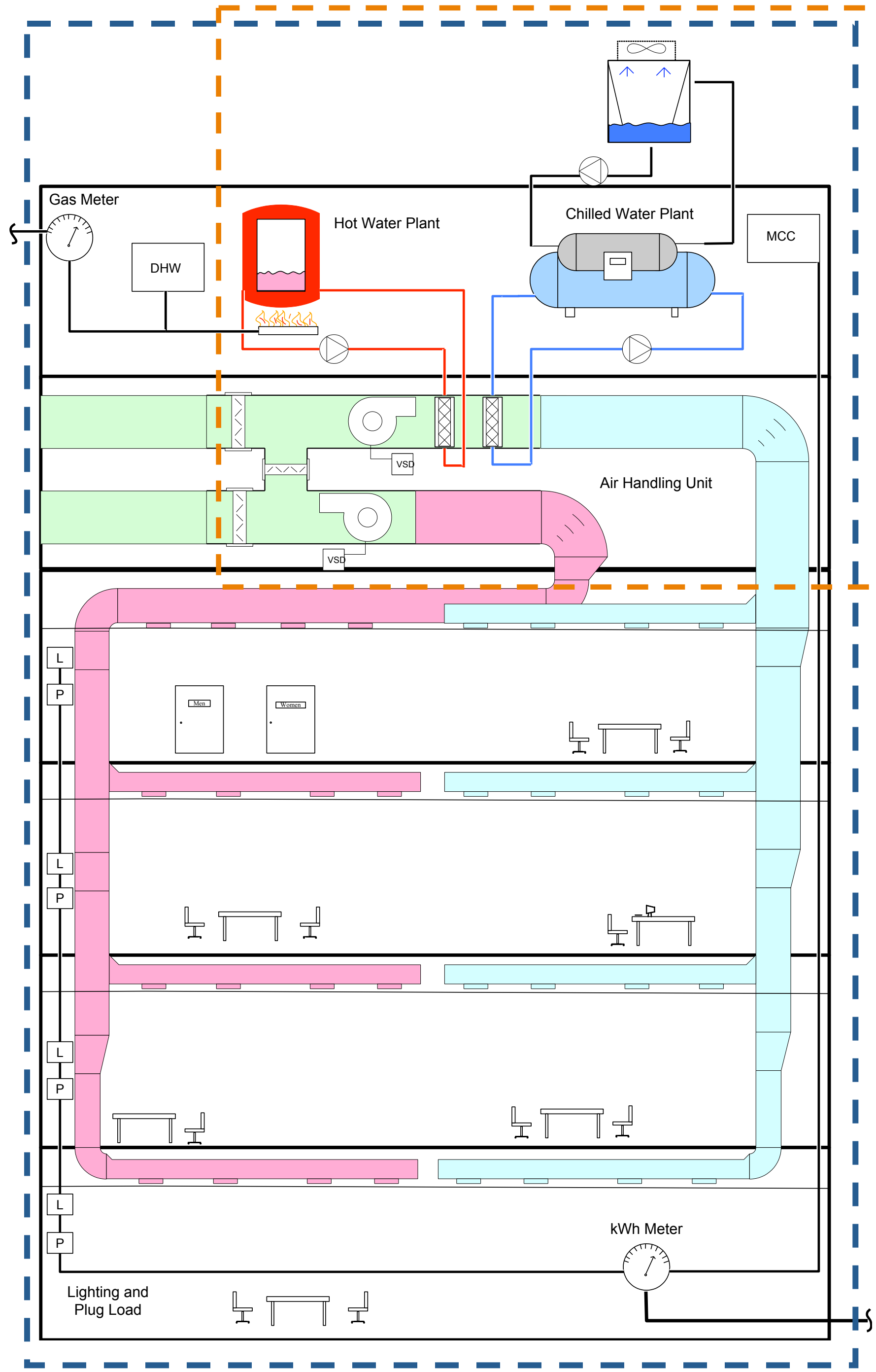
- Options (IPMVP)
  - Option A: Retrofit Isolation
    - Key Parameter Measurement
  - Option B: Retrofit Isolation – All Parameter
    - All Parameter Measurement
  - Option C: Whole Building
  - Option D: Calibrated Simulation

Focus on Building <u>Systems</u>

Measurement Boundary

- Whole Building
  - includes all systems
  - data from main utility meters

- System
  - chiller, CHWP, tower, CWP, HWP, supply & return fans
  - data from submeters, EMS, loggers



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IPMVP Requirements – 2 parts

1) Verify potential to perform (operational verification)
   - ECMs are installed correctly
   - Operate correctly
   - Have potential to generate savings

2) Verify actual performance (quantify savings)

Quantifying Savings

IPMVP Chapter 3:

Energy Savings = Baseline Energy Use – Post-Retrofit Energy Use

± Adjustments

- Adjustments are:
  - Routine
  - Non-Routine

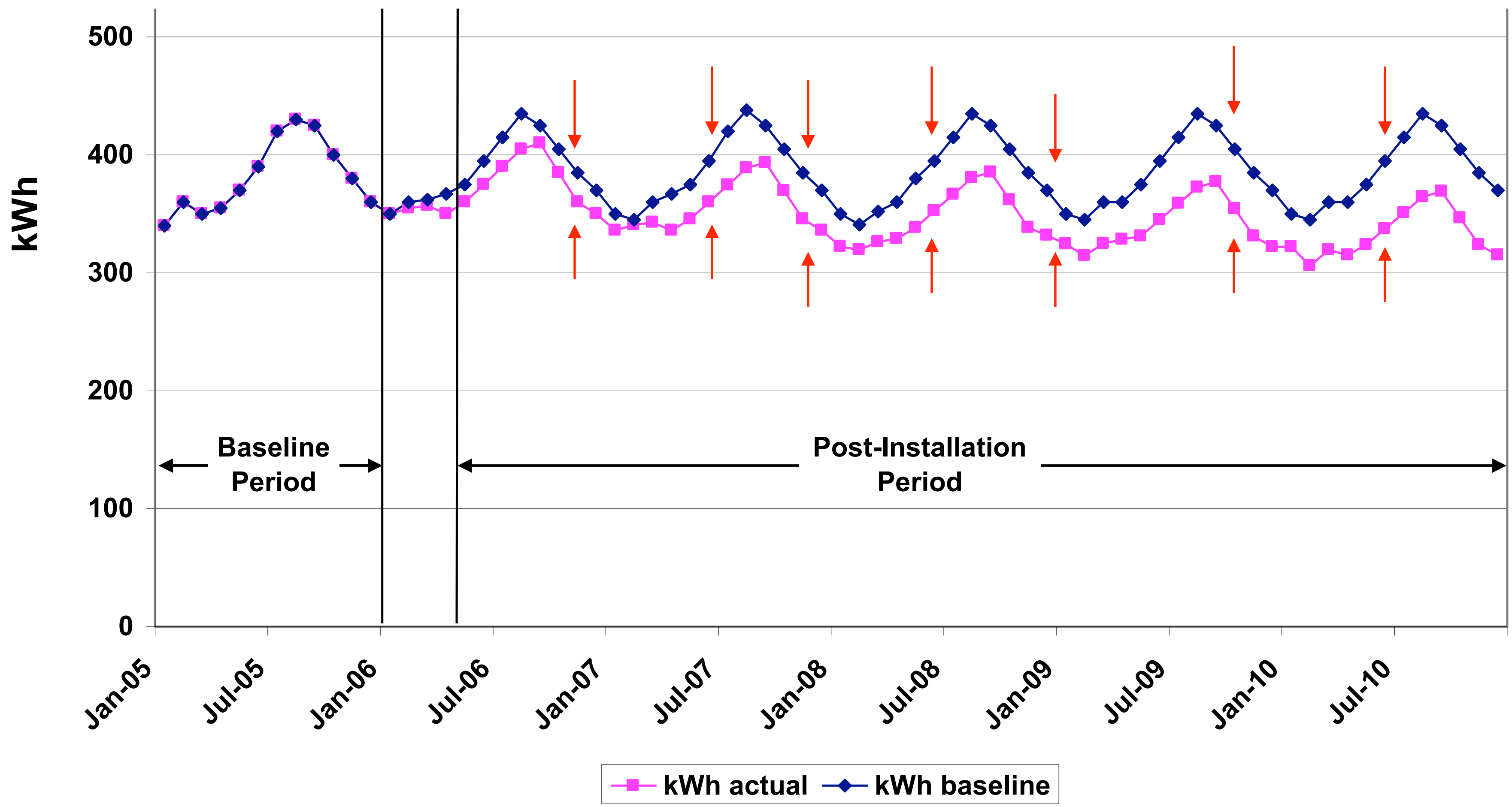
Routine Adjustments

- Normal and expected variations in energy use due to operating conditions, weather, normal production rates, etc.

- Equation becomes:

  Energy Savings = Adjusted Baseline Energy
  – Post-Installation Period Energy
  ± Non-Routine Adjustments

Graphical Concept



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Models

- Baseline energy use is modeled
  - Predictive or empirical models
- Model determines what baseline use would have been under post-install conditions
- Measured post-install use is subtracted from adjusted baseline to calculate Avoided Energy Use
- Normalized Savings are calculated from baseline and post-install energy use under different conditions
  - e.g. typical meteorological year (TMY)
  - requires post-install model as well

Non-Routine Adjustments

- Energy use (or lack of) due to non-routine events, occupancy or equipment changes, etc.
- Examples:
  - Tenant moving in or out
  - Chiller failure and replacement
  - New building loads (office eqp., servers, etc.)

- Remove impact from adjusted baseline
  - Requires measurements & analysis

More IPMVP Requirements

- Collect data through one cycle of operation, or for all modes of operation
  - Baseline and post-installation periods
  - for buildings, does this mean one year?
- Report savings for measurement period only
  - no extrapolation

Issue

- Ex-Ante Savings Conundrum – Who is Right?
  - Peer review
  - Owner's representative
  - EE implementers & evaluators

- Standardize to M&V - one methodology
  - Before-after measurements
  - Acceptable adjustments
  - Was correct data collected, procedure followed?

Case Studies - Context

- Early (2003) BTU program evaluation results not good
  - Poor realization rates (~50%)
    - Savings calculations
    - Persistence
  - EBCx programs not cost-effective

- Monitoring Based Commissioning Program Projects (2004 - present)
  - Integrated M&V with EBCx projects

Case Study #1 – Soda Hall

- UC Berkeley's Computer Science Department (24/7 operation)
- 109,000 ft^2
- Central Plant (2 - 215 ton chillers & associated equipment)
- Steam to hot water heating
- 3 Main VAV AHUs,
  - AHU1 serves building core,
  - AHUs 3 and 4 serve the perimeter, with hot water reheat

Soda Hall Findings

System	Measure No.	Description	Implementation Date	Savings: Energy, kWh/yr	Savings: Energy, lbs/yr	Savings: Dollars, $/yr	Cost, $	Payback, yr
AHU-1	AHU1-2	Resume supply air temperature reset control and return economizer to normal operation	10/25/2006	129,800	266,250	$19,004	$1,550	0.1
	AHU1-3	Repair/replace VFDs in return fans	10/25/2006	34,308		$4,460	$7,000	1.6
	AHU1-4	Reduce high minimum VAV box damper position	3/9/2006	46,300	119,300	$6,973	$15,250	2.2
AHUs 3 & 4	AHU3-2 & AHU4-2	Option 2: Reduce high minimum VAV box damper position	3/9/2006	30,600	2,328,100	$22,603	$17,250	0.8
	AHU3-3 & AHU4-3	Re-establish scheduled fan operation and VAV AHU-3 (includes repair/replace VFD on return fan EF-17), AHU-4 (includes repair/replace VFDs on supply SF-18 and return EF-19 fans, and elimination of low VFD speed setting during the day)	10/25/2006	242,000		$31,460	$14,000	0.4
	Total			**483,008**	**2,713,650**	**$84,500**	**$55,050**	0.7
			Percentage Savings	10%	51%	14%		
			Utility Data	Steam	5,325,717	lbs		
				Electricity	4,871,678	kWhr		
				Cost	$621,575			

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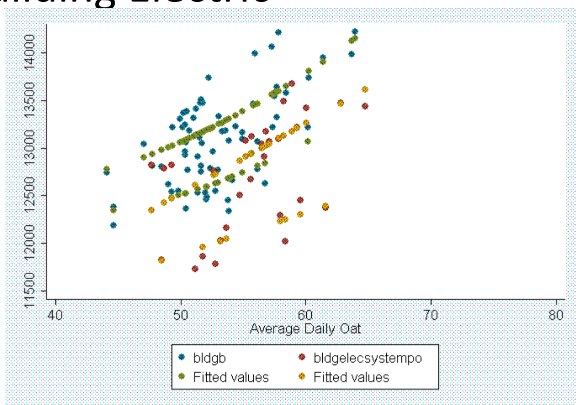
M&V Approach for Soda Hall

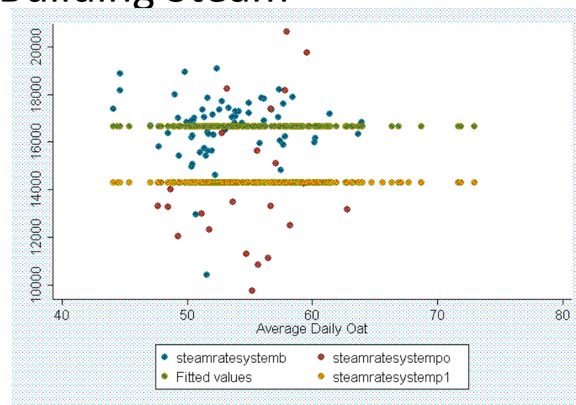
- Resources:
  - Whole-building electric and steam meters present
  - EMS that trends all points at 1 min (COV) intervals
  - 6-month history of data
- EBCx measures in AHU and Chilled Water Systems
  - Electric and steam savings
- Building has very high EUI
  - unsure if can "see" savings at whole building level
- M&V Approach: Regression Modeling
  - Option B – applied at systems level (electric only)
  - Option C – whole building level (electric and steam)

Baseline Model: Soda Hall

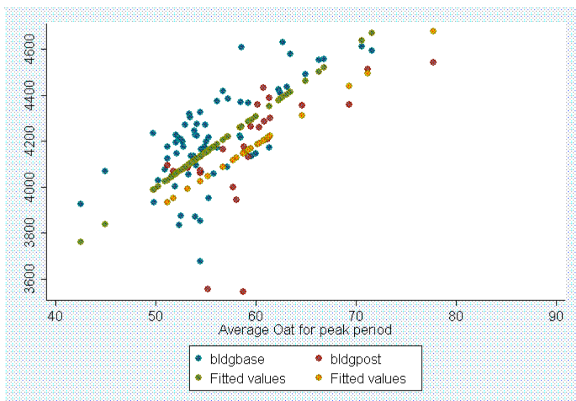
Building Electric



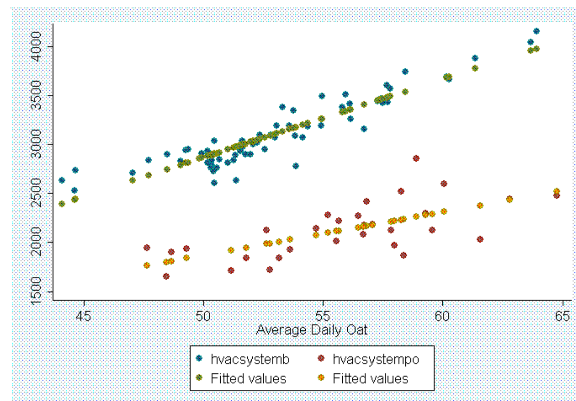
Building Steam



Peak Period Electric



HVAC System Electric



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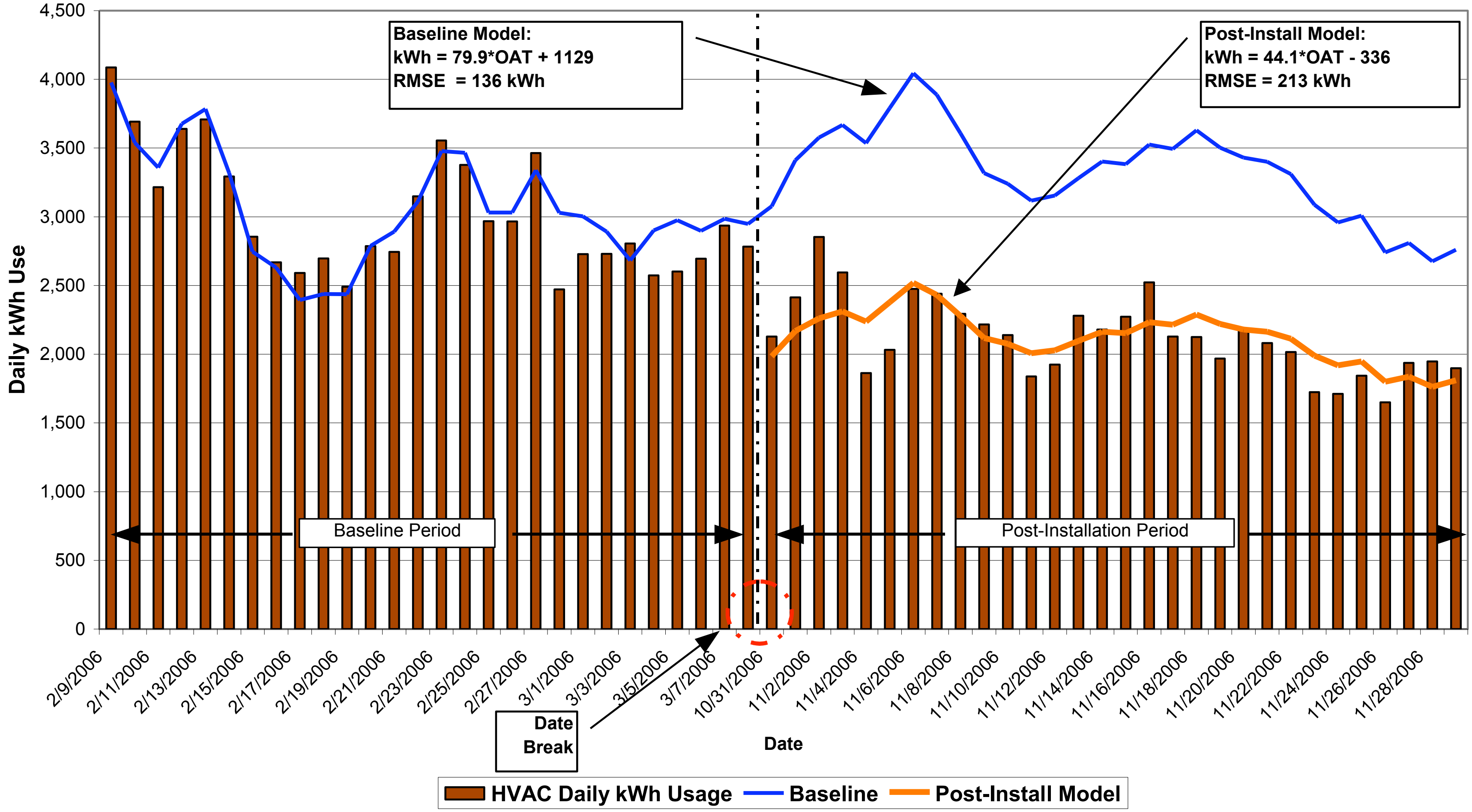
Soda Hall M&V: HVAC Systems



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Soda Hall: Estimated vs. Verified Savings

Source	Estimated Savings*	Verified Savings**	
		Whole Building	HVAC System
kWh	483,008	216,716	462,472
kW	-	22	50
Lbs. Steam	2,713,650	854,407	

* based on eQUEST model

** based on baseline and post-installation measurements and TMY OAT data

Case Study #2 – Shields Library

- UC Davis Undergraduate Library
- 400,072 ft^2
- 5 electric meters
- Chilled Water and Steam provided by campus central plant
  - 2 CHW service entrances, variable volume
  - 2 steam meters to 3 HW services (3 HX)
- 11 AHU, 3 VAV, 8 CAV

Shields Library RCx Findings

System	Description of Deficiencies/Findings
AC01 & AC02	• Excessive fan speed due to failure to meet static pressure set point • Economizer malfunction • Simultaneous heating and cooling in air stream
AC21, AC25, AC25, AC51, AC53, AC54, AH1, AH2, AH3	• Economizer Repair • Economizer Control Optimization • Supply Air Temperature Reset with Occupancy Schedule
CHW & HW Pumps	• Chilled water supply temp set point reset • Chilled water pump lockout • Reset CHW EOL pressure set point

- limited savings estimates prior to measure implementation

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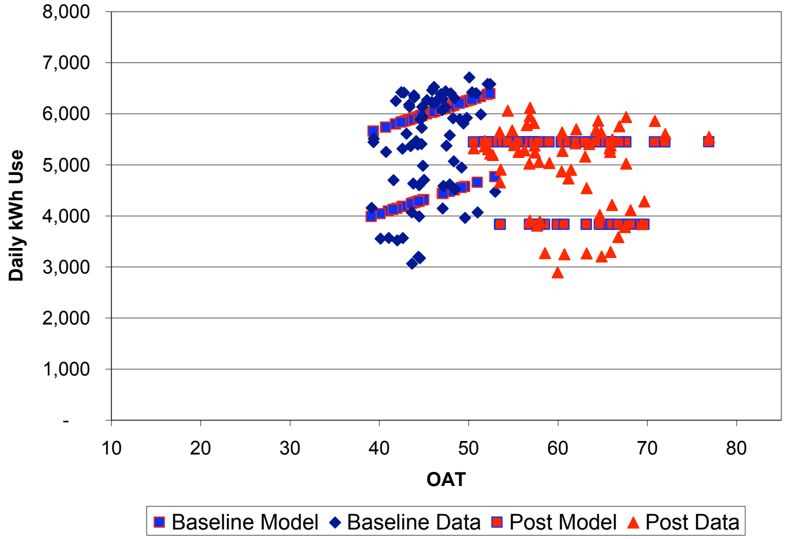
M&V Approach for Shields Library

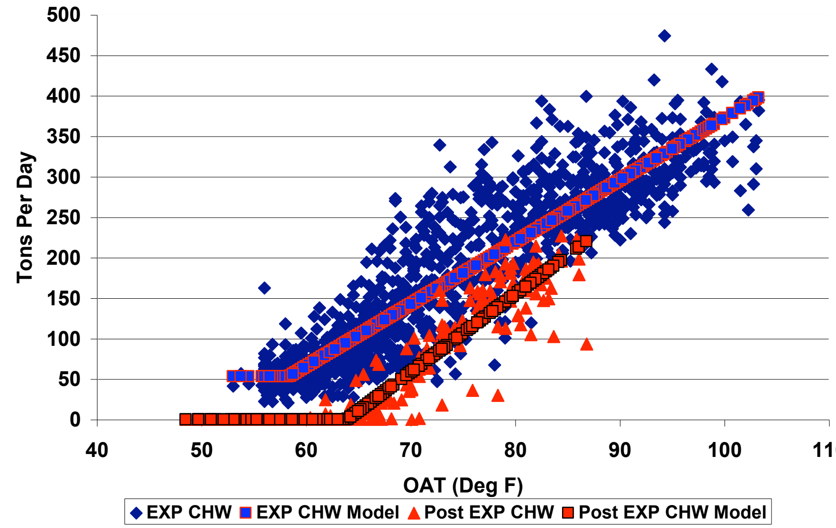
- Whole-building meters present:
  - 5 electric meters
  - 2 CHW meters (installed as part of project)
  - 3 HW meters (installed as part of project)
- EMS that trends all points at 5 min intervals
- RCx measures in AHU, CHW and HW pumps
  - Electric, chilled water, and hot water savings
- M&V Approach:
  - Option C – applied to selected meters

Shields Library: M&V Models

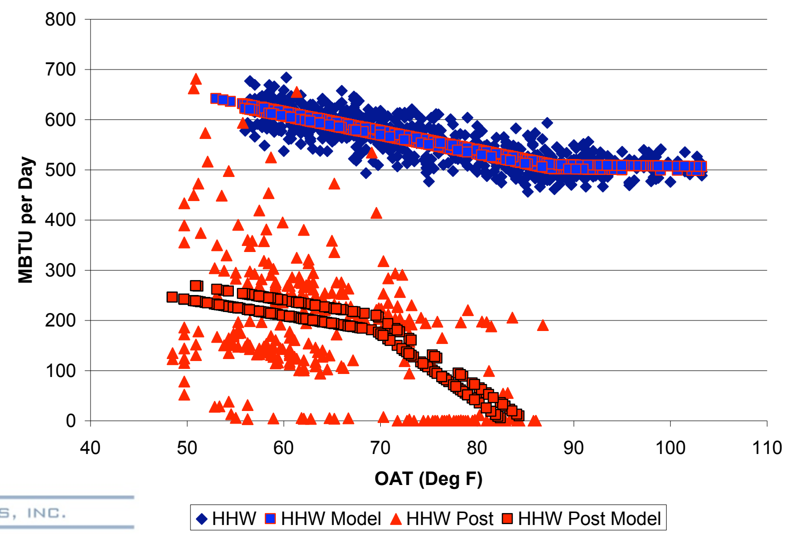
Electric



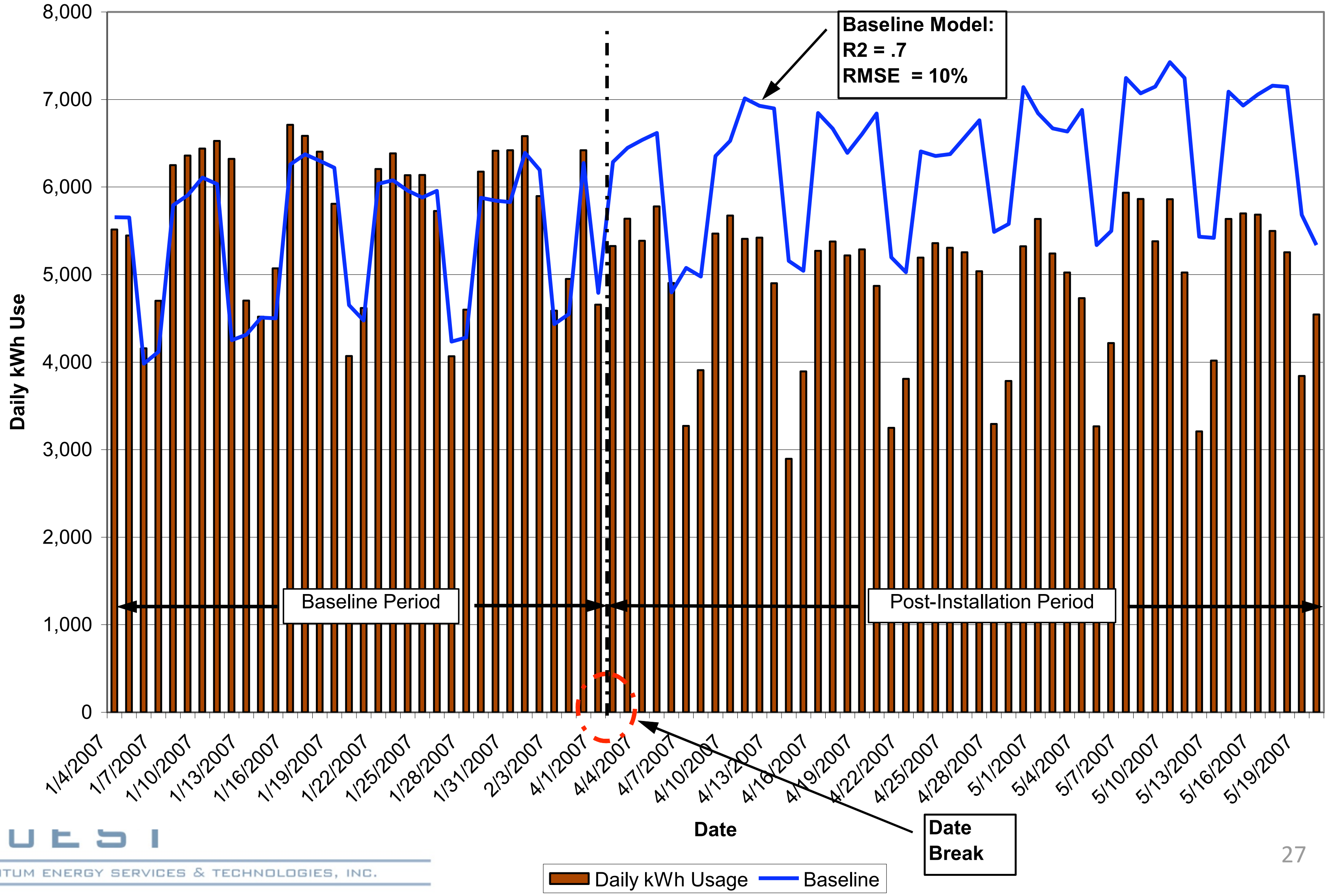
Chilled Water



Steam



Shields Library: 480V Electric Meter Savings



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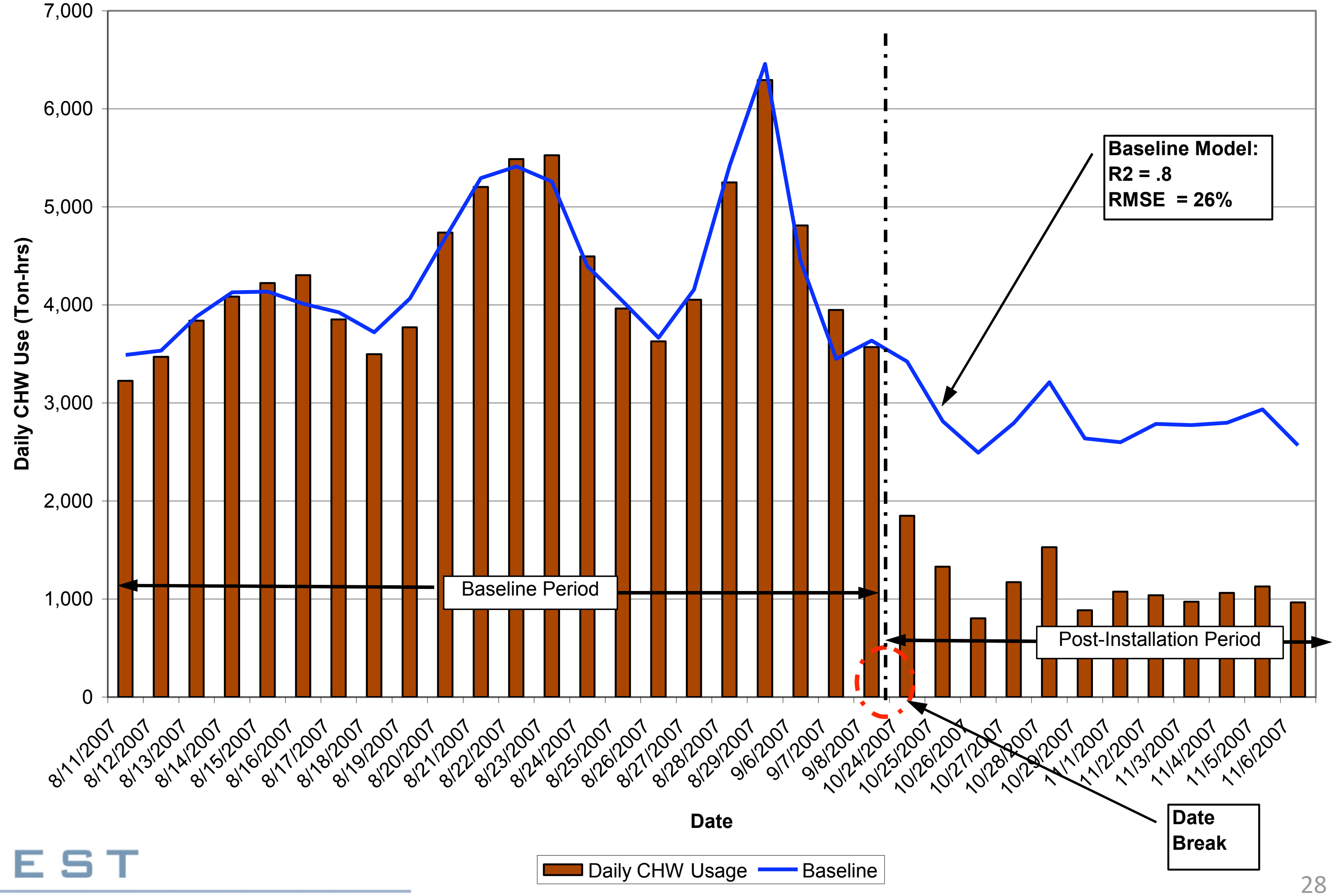
Shields Library: Chilled Water Savings



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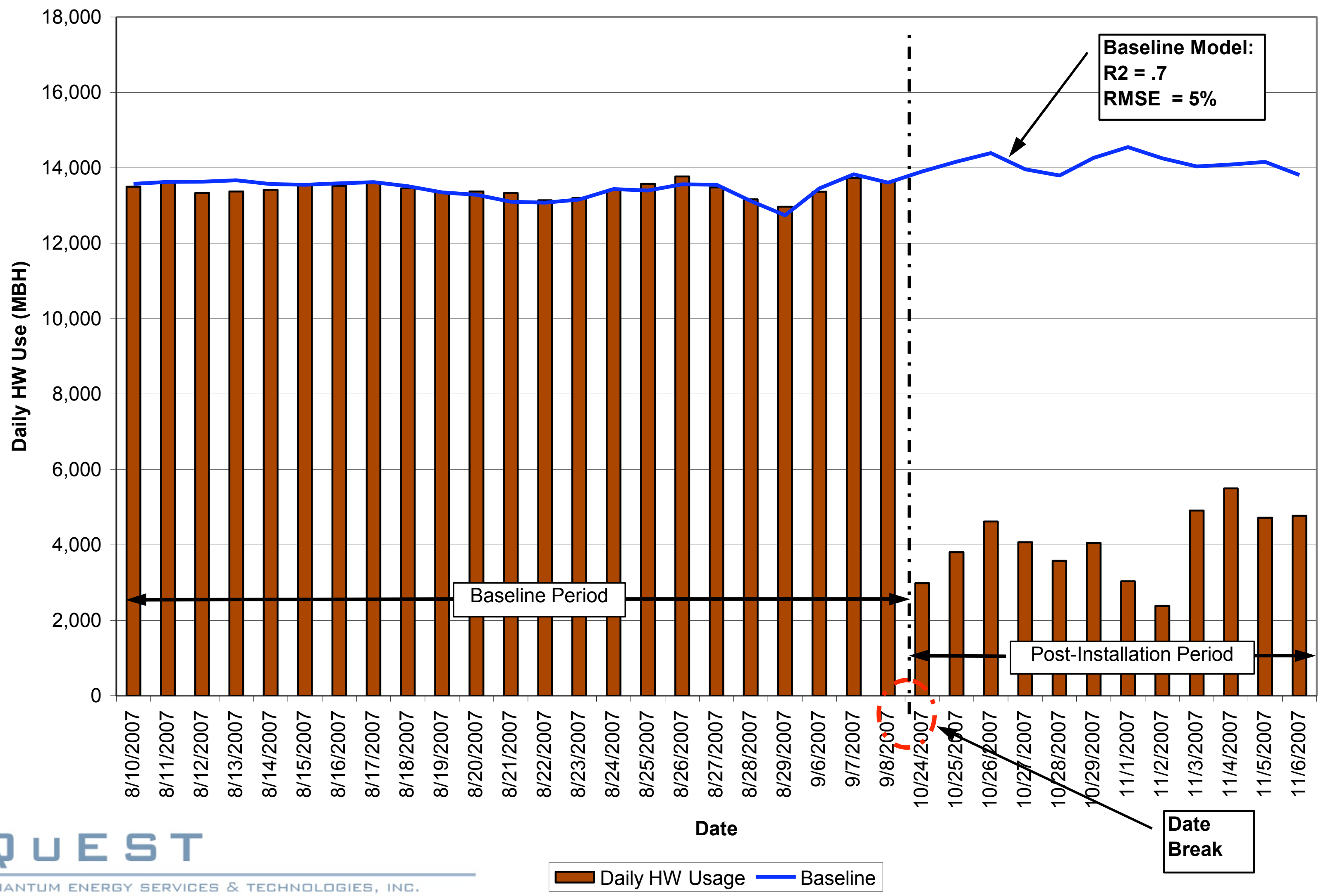
Shields Library: Hot Water Savings



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Costs

Building	Metering Costs	MBCx Agent Costs	In-House Costs	Total
Soda Hall	$ 4,442	$ 62,160	$ 51,087	$ 117,689
Tan Hall	$ 22,573	$ 53,000	$ 15,300	$ 90,873
Shields Library	$ 26,000	$ 96,795	$ 57,757	$ 180,552

- Including M&V, projects remained cost-effective:
  - Soda Hall: 1.7 year payback
  - Tan Hall: 0.7 year payback
  - Shields Library: 1.0 year payback

Evaluated project realization rates: 105% electric, 106% gas

- Added costs of metering and M&V analysis did not overburden project costs

- MBCx approach should be viable in private sector
  - Existing electric meters
  - Sophisticated BAS systems

Outcomes of MBCx Work

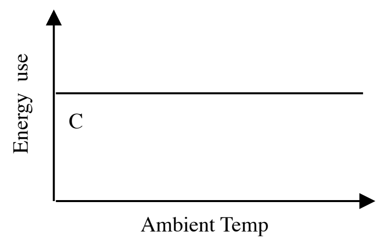
- Changes to MBCx program
  - M&V required
    - 3 months data, baseline and post
- Practical Guidelines
  - California Commissioning Collaborative
    - Energy Modeling with Interval Data
    - www.cacx.org
  - Bonneville Power Administration
    - Energy Modeling Protocol
    - Other M&V protocols
    - www.conduitnw.org

Outcomes, cont.

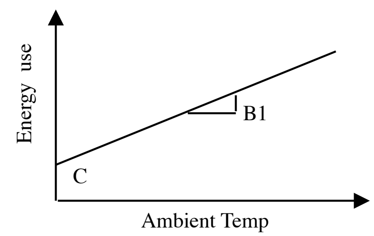
- Market Awareness
  - UCB, UCD
    - desire to track energy use & maintain savings
  - IPMVP Committee: Monitoring and Targeting
  - “Data Mining” Companies
    - Software as a Service
    - Dashboards

- Energy Modeling Tools
  - QuEST Energy Modeling Spreadsheet
  - M&V Tool for Universal Translator
    - alpha in 2012, beta early 2013

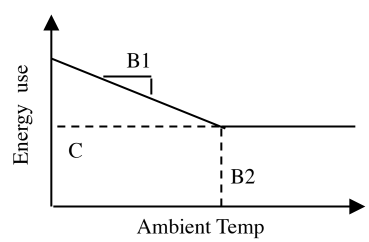
Regression Energy Modeling Method



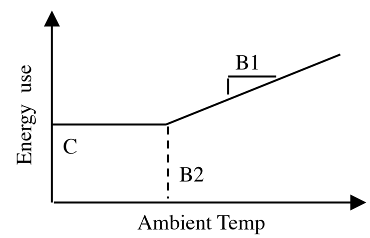
1-parameter model



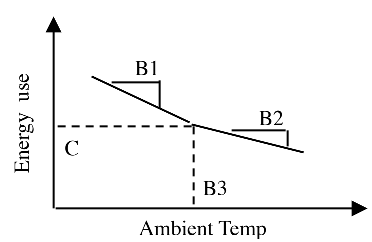
2-parameter model



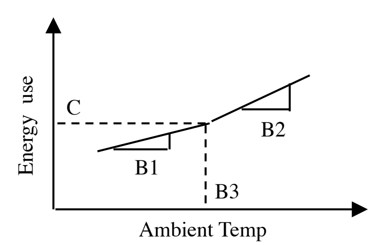
3-parameter model (heating)



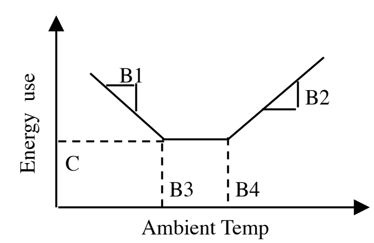
3-parameter model (cooling)



4-parameter model (heating)



4-parameter model (cooling)

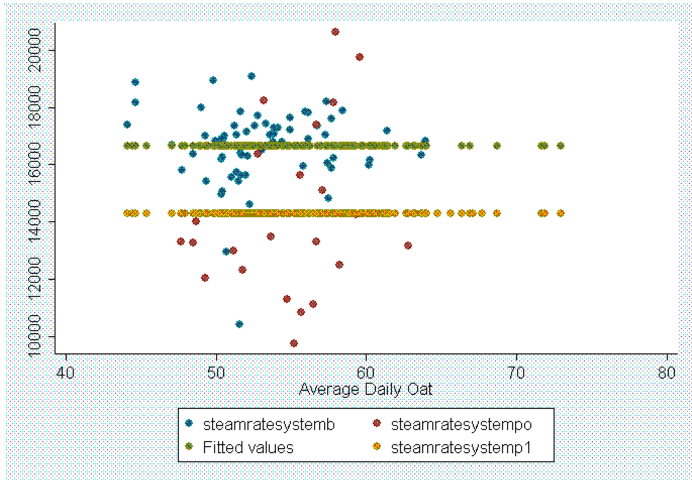


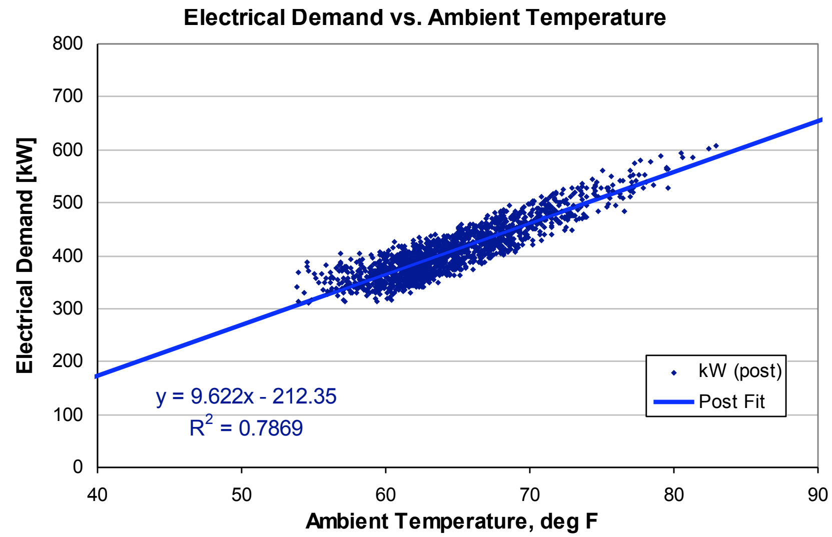
5-parameter model

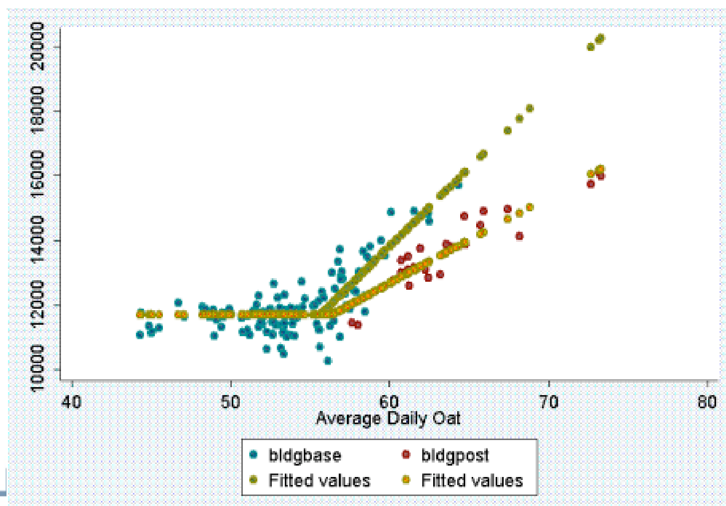
Applicability

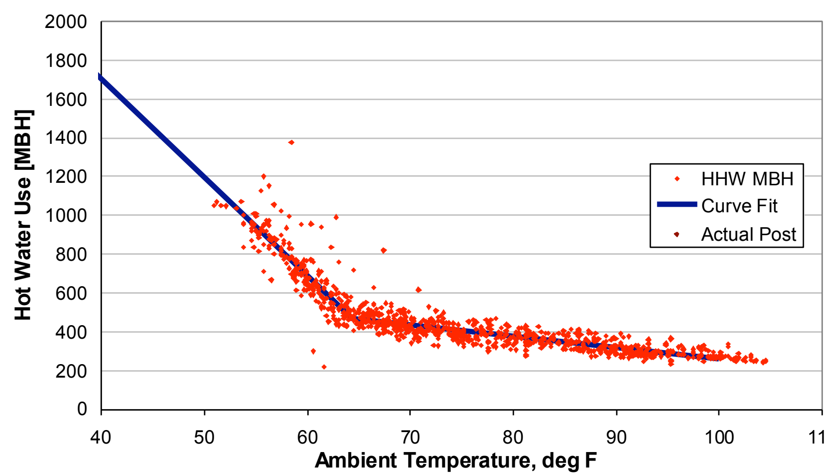
- Whole Building Meter (one or multiple)
  - IPMVP Option C
- Building Subsystems
  - HVAC System
  - Chilled Water System
  - Etc.
  - IPMVP Option B

Model Examples









Developing Models

- General Procedure
  - Plot data
  - Select model type (1-P, 2-P, 3-P Cooling, etc.)
  - Select change point
  - Perform regressions (averages where needed)
  - Calculate CV & NMBE
  - Adjust change point
  - Perform new regressions
  - Calculate CV & NMBE, compare with run #1
  - Iterate to lowest CV & NMBE

Assess Baseline Model

- Develop different energy use models
- Select model that best fits data (low NMBE, CV)
- Run uncertainty assessment
  - Determines if model can determine savings within reasonable uncertainty
  - May need to select alternate approach
- Finalize approach
- Decide how long to measure in post-installation period (Reporting Period)
- Document in M&V Plan

Uncertainty Assessment

- ASHRAE G14, Annex B, Eqn. B-15 (also VoS Guide, cacx.org)
  - Fractional Savings Uncertainty , $\Delta E_{save,m}/E_{save,m}$

- For "weather models with correlated residuals"

$$\frac{\Delta E_{save,m}}{E_{save,m}} = t \cdot \frac{1.26 \cdot CV \left[\frac{n}{n'} \left(1 + \frac{2}{n'} \right) \frac{1}{m} \right]^{1/2}}{F}$$

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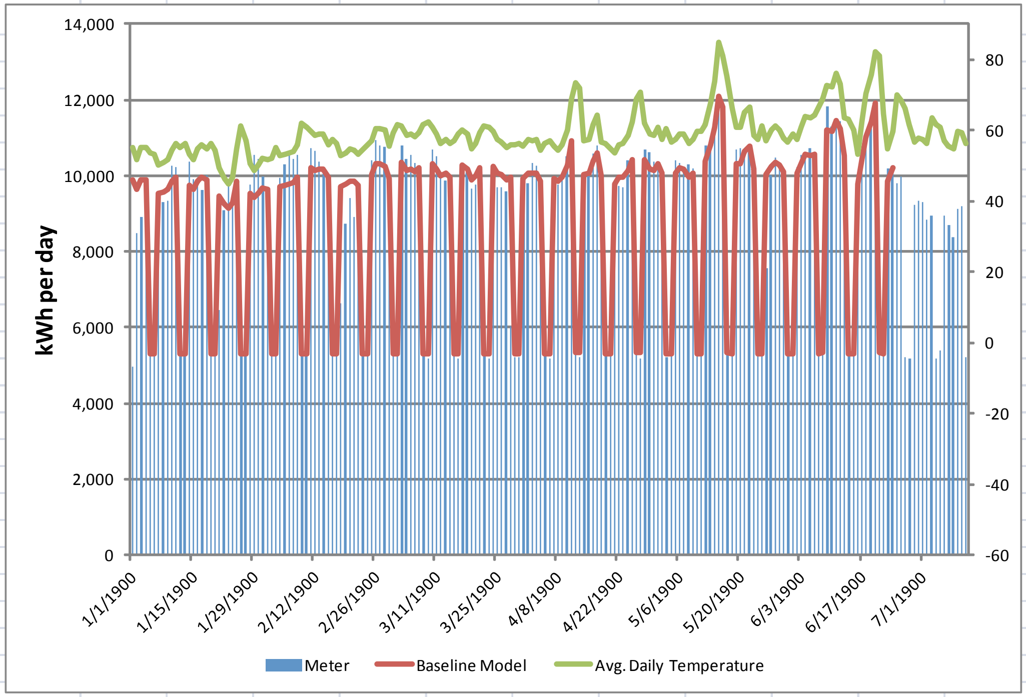
Uncertainty Example

DateTime	Avg. Daily Temperature	Meter	Baseline Model
1/1/08	55	4967	9886.7
1/2/08	52	8465	9636.5
1/3/08	55	8896	9883.6
1/4/08	55	8654	9882.3
1/5/08	54	5279	5290.9
1/6/08	53	5253	5290.2
1/7/08	50	9433	9533.6
1/8/08	51	9315	9573.3
1/9/08	52	9346	9639.9
1/10/08	54	10276	9844.5
1/11/08	56	10222	9970.5
1/12/08	55	5368	5293.9
1/13/08	56	5335	5295.4
1/14/08	53	10379	9756.4
1/15/08	52	9904	9649.7
1/16/08	55	9957	9856.3
1/17/08	56	9614	9946.6
1/18/08	55	9997	9875.1
1/19/08	56	5337	5295.9
1/20/08	54	5287	5292.3
1/21/08	49	6460	9476.4
1/22/08	46	9071	9254.3
1/23/08	45	9715	9125.3
1/24/08	47	9439	9282.1
1/25/08	55	9412	9862.3
1/26/08	61	5499	5304.6
1/27/08	57	5437	5297.4
1/28/08	50	9759	9547.3
1/29/08	49	10546	9417.9
1/30/08	50	10427	9524.2
1/31/08	52	9982	9667.0
2/1/08	52	9698	9641.3
2/2/08	52	5436	5287.8
2/3/08	55	5327	5293.5
2/4/08	53	9941	9717.2
2/5/08	53	10289	9743.7
2/6/08	54	10565	9777.8
2/7/08	54	10426	9818.7
2/8/08	56	10541	9946.1
2/9/08	62	5417	5306.0
2/10/08	61	5334	5304.1
2/11/08	59	10710	10223.4
2/12/08	59	10649	10150.6



QuEST
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ENERGY MODELING SPREADSHEET

Inputs

Project Date (End of Baseline Period)	6/24/08 12:00 AM
Required Confidence Level	90%
Anticipated Number of Post Points	365
Anticipated Savings Percentage	10.0%

DEVSQ residuals 30426.19095

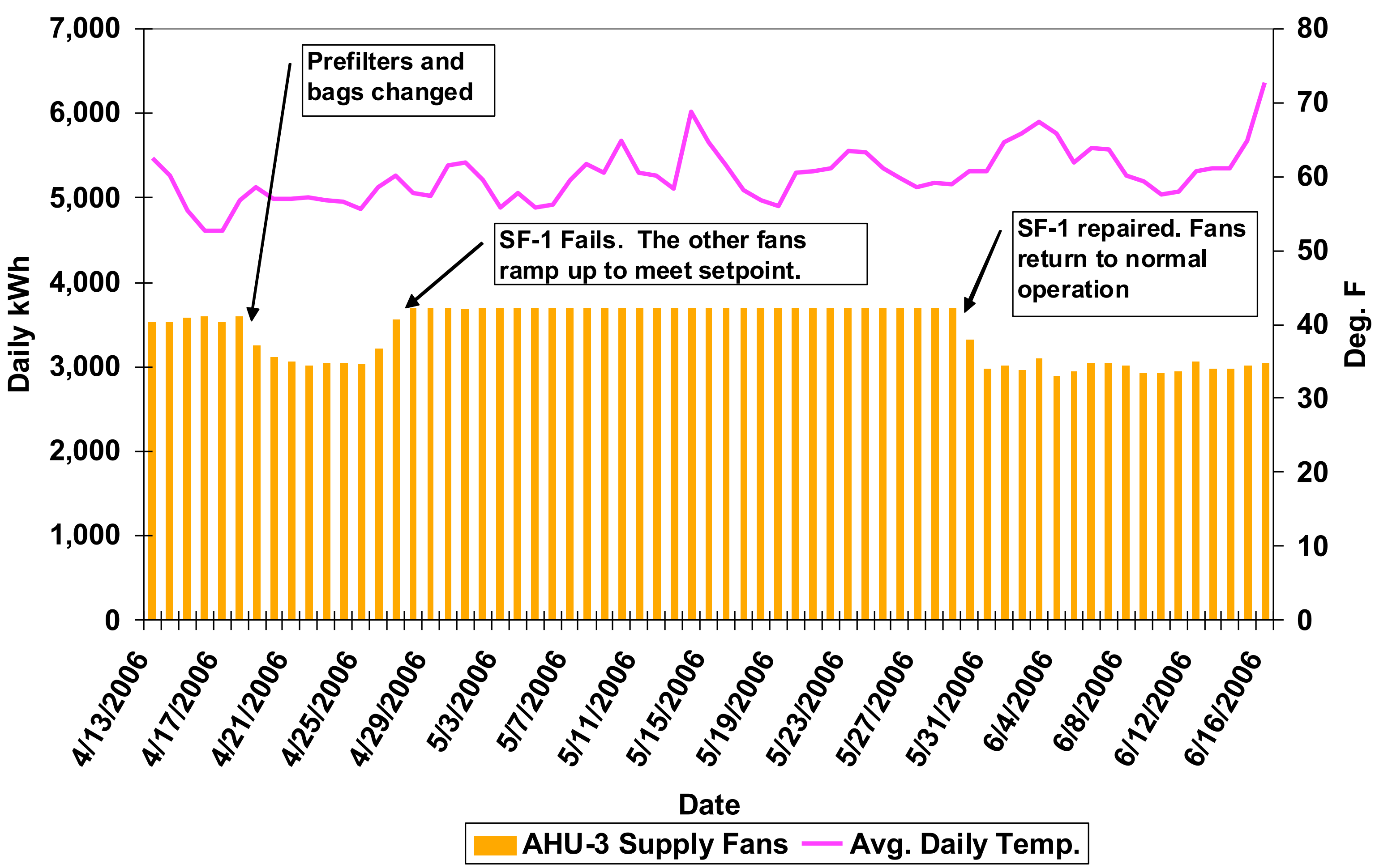
Outputs

Change Point Temp	All Data
R-squared	-2.19
CV-RMSE	47.4%
Fractional Savings Uncertainty	76.5%
Savings Range	10.0% ± 3.8%

Useful Software

- QuEST Change-Point Model Spreadsheets
  - www.quest-world.com
  - Excel-based, change-points, and $\Delta E_{save,m}/E_{save,m}$
- Energy Explorer
  - Automatically determines best fit of change-point models to data, makes charts, calculates savings, uncertainty, etc.
  - Source: Prof. Kelly Kissock, University of Dayton
- ASHRAE Inverse Modeling Toolkit (RP1050)
  - Purchased with Research Project 1050
  - DOS-based, source and executable files
  - Change-point models, no uncertainty calculations

Non-Routine Adjustments



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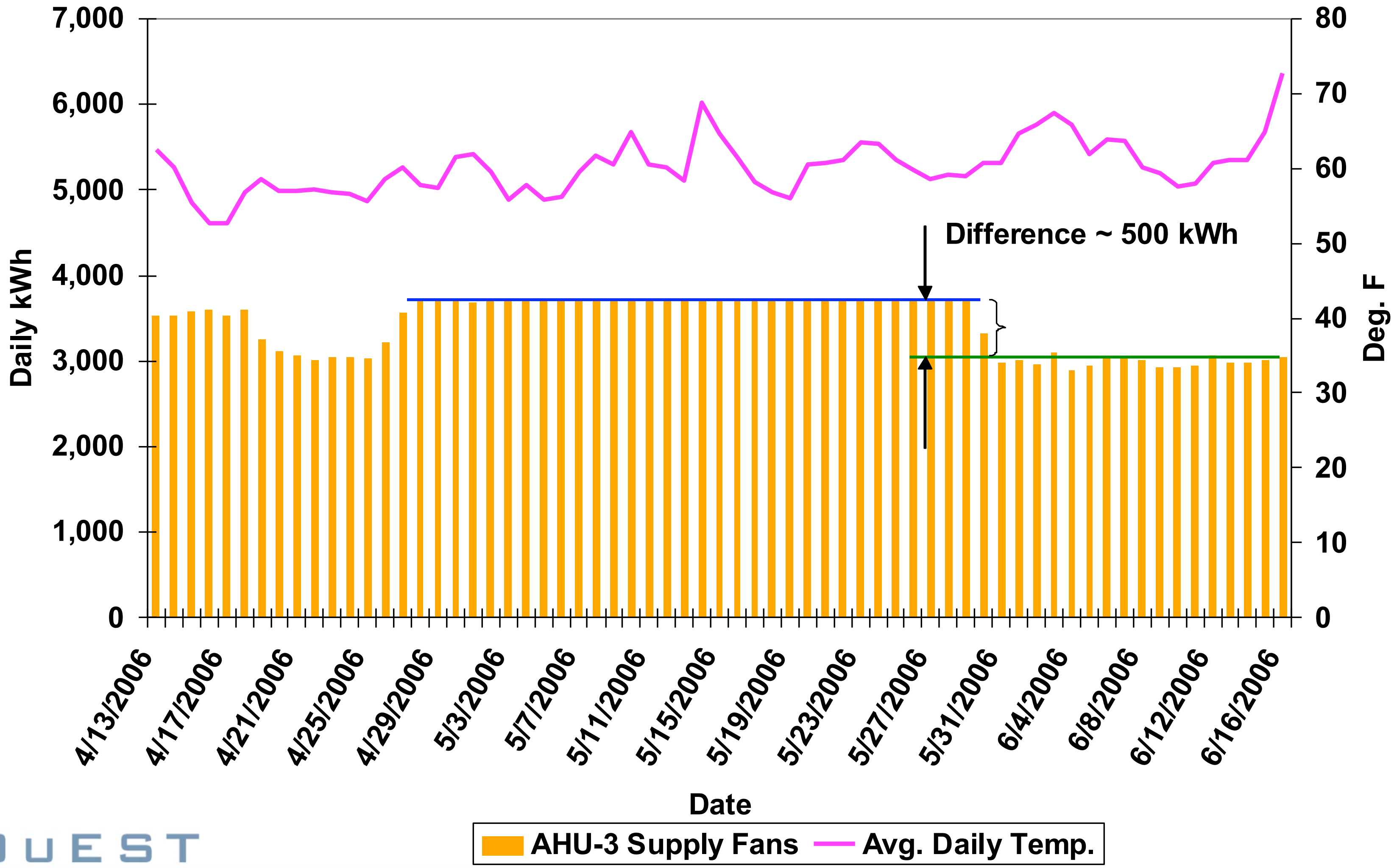
Non-Routine Adjustment

- Temporary or permanent
- Energy use patterns can reveal impact
- Identify non-routine operation period
  - Investigate to determine & document cause
- Develop a model that fits the non-routine usage pattern
  - Average, 2-P, 3-P, etc.
- Subtract from baseline or post usage

Non-Routine Adjustment



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Regression Method Problems

- Data hard to collect and prepare
- Modeling techniques
  - difficult & time-consuming
- Uncertainty analysis
  - difficult & time-consuming

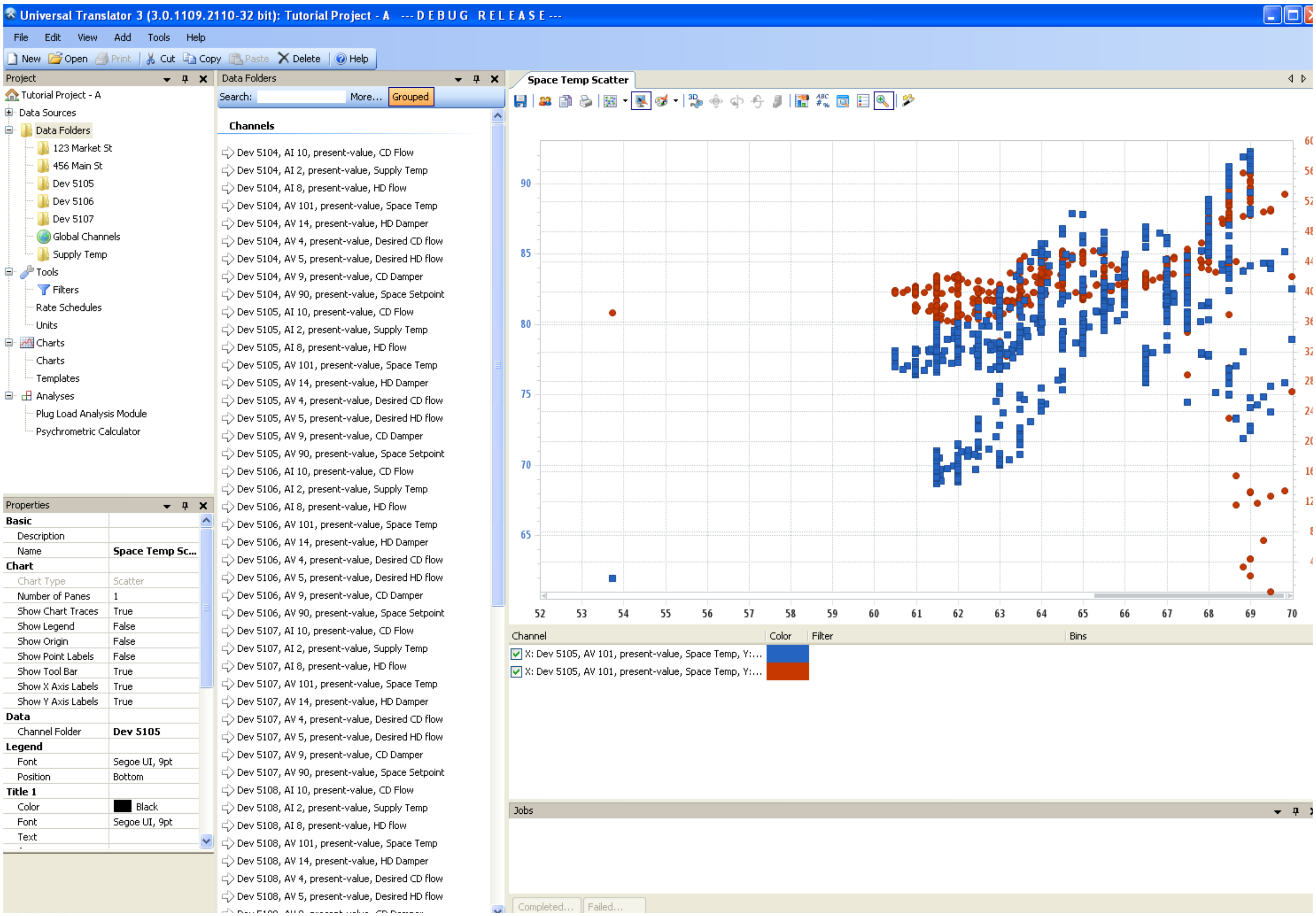
UT M&V Tool Project

- Funded by CEC PIER
- Develop an analysis module for the Universal Translator
  - Leverage UT's data preparation capability
  - Enable complete M&V savings analysis
    - Using energy modeling method
  - Apply to whole-building or systems data

UT M&V Tool Research Questions

- Create & assess regression models
  - Applied to baseline and post-install periods
  - Usefulness of additional regression model types
    - 6-parameter
    - Polynomial
- How much data needed for model development?
- Calculate savings & uncertainty
  - For measurement period: Avoided energy use
  - Annual (extrapolation): Normalized savings

UT User Interface



QUEST

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Questions?

Equipment and End-Use Metering

- Inspired by ASHRAE G14 Retrofit Isolation

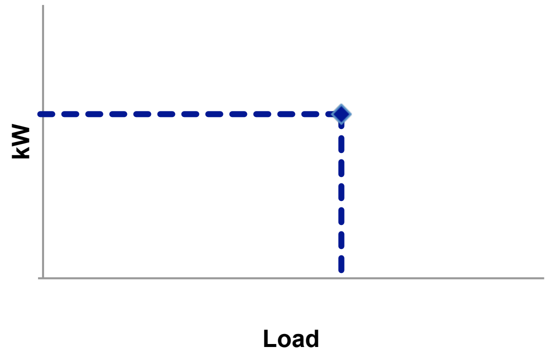
- Characterize baseline equipment load and schedule operation
  - Constant
  - Variable
- Determine impact of ECM on load & schedule
  - Changes load or schedule or both
- Characterize post-install operation
- Define analysis algorithms
- Identify data required
- Execute plan

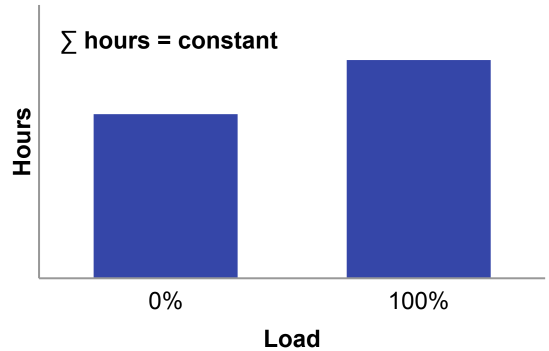
Applicability

- Loads that may be isolated and measured
  - Air or water flow, heating Btu/h, cooling tons, etc.
  - Relationship to kW known or may be developed
- Model variable hours in load frequency distributions
  - # hours in load bins
- Energy flows: few or straightforward
- Negligible/ignorable interactive effects with other equipment
- Systems of multiple pieces of equipment with energy characteristics similar to single end-use

End-Use Metering

- Constant Load, Constant Schedule

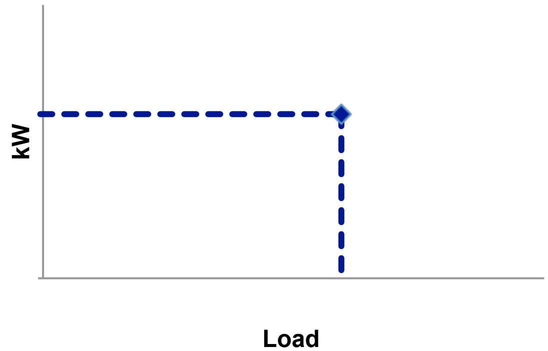


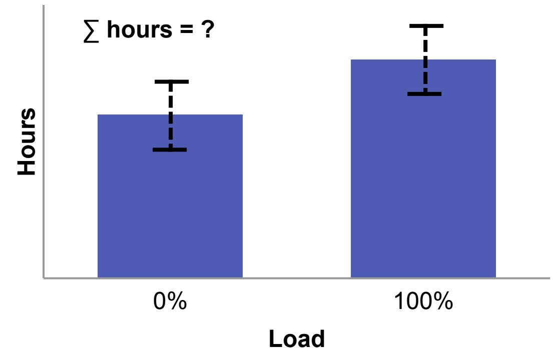


- Degree of “constant” defined by user
  - Coef. Variation of Standard Deviation: CV(STD) ≤ 5%
- Examples
  - Lighting under time clock control
  - CRAH unit fan 24/7 operation

End-Use Metering

- Constant Load, Variable Schedule





- Load is constant, but unknown hours-of-use
- Examples:
  - Lighting controlled with occupancy sensors
  - Constant speed cooling tower fans – hours vary with ambient temperature

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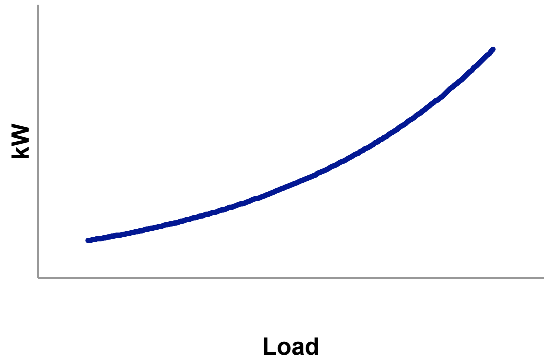
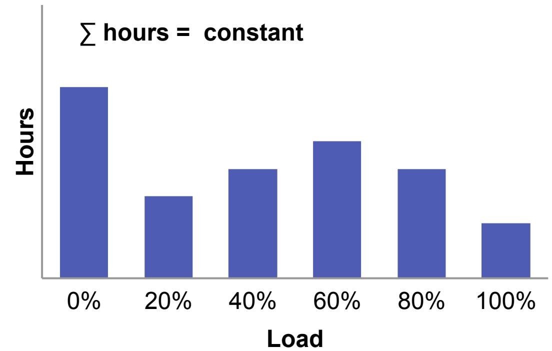
End-Use Metering

- Variable Load, Constant Schedule

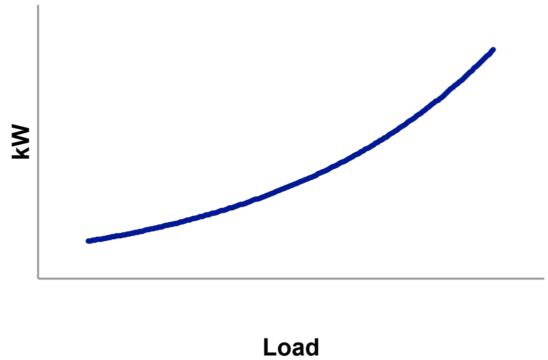


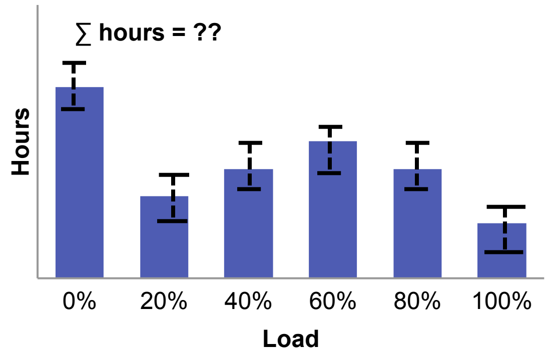


- kW varies with load (cfm, ton, speed, etc.)
- Total hours constant, distributed over several load bins
- Examples
  - WW treatment blowers maintaining constant DO levels (24/7)
  - CRAC unit operation (split system, condenser on roof)

End-Use Metering

- Variable Load, Variable Schedule





- Hours-of-use in each bin and total are unknown
- Examples
  - Chilled water system maintaining CHWST reset schedule
  - Industrial VFD compressed air system

Algorithm

1. Identify baseline operation category
2. Determine impact of ECM
   a. *Changes load, changes schedule*
   b. *Changes load or schedule from constant to variable*
3. Identify post-installation operation category
4. Select equation, define analysis procedure
5. Determine relationships between load & hours-of-use, and other parameters
   - *e.g. T, cfm, gpm, speed, tons, etc.*
6. Collect baseline and post-install data
7. Calculate savings

Equations – Examples

- CLTS
  - Changes load $$kWh_{saved} = \left(Eff_{base} - Eff_{post}\right) \cdot Q_{post} \cdot HRS_{post}$$
  - Changes hours-of-use
    $$kWh_{saved} = kW_{base} \cdot \left(HRS_{base} - HRS_{post}\right)$$
  - Changes load from constant to variable
    $$kWh_{saved} = kW_{base} \cdot HRS - \sum_i \left[kW_{post,i} \cdot HRS_i\right]$$
  - Changes hours-of-use from constant to variable
    $$kWh_{saved} = kW_{base} \cdot HRS_{base} - kW_{base} \sum_i HRS_{post,i}$$
    $$HRS_{base} \neq HRS_{post} \qquad HRS_{post} = \sum_i HRS_{post,i}$$

Measurement Plan

- Option A
  - measure key parameter
  - estimate non-key parameter
    - nameplate, spec., etc.
- Option B
  - measure all parameters

- Equations define data requirements
  - baseline & post-installation measurements
- Shortcuts also identified
  - If load not affected, measure once
    - Baseline or post-install period

Advantages of End-Use Protocol

- M&V is extension of methods used to calculate ex-ante savings
- Allows use of technical (not measured) info. (Option A)
- Many required measurements may be cost-effectively obtained
- Can apply to more complicated systems, if operation characteristics same
- Can quantify savings uncertainty, if required

Disadvantages

- Not practical for multiple ECMs throughout a facility
- Does not account for savings interactions
  - e.g. cooling savings from a lighting retrofit
- Not well applied to end-uses with highly random load and schedule characteristics